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THE EARLY CAMBRIAN VOLCANICS FROM RED CREEK, EASTERN MT LOFTY RANGES, SOUTH AUSTRALIA

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Summary

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In the Red Creek area of the eastern Mt Lofty Ranges, Early Cambrian lavas, tuffs and volcaniclastic sediments are interbedded with the top 270 m of the Heatherdale Shale, the top member of the Normanville Group. Tuffs and volcaniclastic siltstones extend up into the basal 60 m of the conformably overlying Carrickalinga Head Formation, the basal unit of the Kanmantoo Group. Several lava flows of trachybasalts, one of which exhibits pillows, occur about 100 m below the top of the Heatherdale Shale. The volcanics at Red Creek appear to be at a slightly higher stratigraphic level than the Truro Volcanics, the type section of which is 24 km to the NNW of Red Creek. It is proposed that the lavas at Red Creek represent a flow of hawaiite composition from a central volcanic complex, closely analogous to that of the Truro Volcanics but not necessarily from the same centre or erupted at exactly the same time. Geochemical data indicate that both the volcanics at Red Creek and the Truro Volcanics belong to the same alkaline Early Cambrian "within plate" volcanic province, which may be linked genetically with other Cambrian mafic alkaline provinces such as the Yumali/Coonalpyn area. It is suggested that the closest tectonic analogy for these provinces is that of a rifted continental margin as proposed for the Tertiary intraplate volcanic province of eastern Australia.

KEY WORDS: Early Cambrian volcanics, hawaiite, Mt Lofty Ranges, Normanville Group, Kanmantoo Group

Introduction

This paper is a progress report on work on the Early Cambrian volcanics generally known as the Truro Volcanics of the eastern Mt Lofty Ranges. The Truro Volcanics are important in that, although they are limited both in stratigraphic and geographic extent, they represent the most extensive outcrops of volcanics in the Cambrian sequences of the Stansbury Basin/Kanmantoo Trough area. As described below, volcanics in the Red Creek area extend from within the Heatherdale Shale, the top member of the Normanville Group, up into the Carrickalinga Head Formation, the basal member of the Kanmantoo Group. Hence a study of the Truro Volcanics is important in the determination of the stratotectonic setting of the Kanmantoo Group transition which has been interpreted in various ways as set out below.

Von der Borch (1980) considered the Kanmantoo Group sediments to be the initial phase of fully developed continental margin sedimentation which typified the eastern flank of cratonic Australia during most of the Palaeozoic. Turner & Foden (1990) suggested that this phase was marked by renewed mafic igneous activity in the form of the Truro Volcanics. The basal part of the Carrickalinga Head Formation at Carrickalinga Head lies north of Normanville where von der Borch (1980) proposed that the Houghton Anticlinal Zone acted as a separating feature between shallow-water sediments to the west and continental slope and rise environments to the east. Scheibner (1986, Fig. 4) implied that the Kanmantoo Group sediments were at least in part deposited on oceanic crust and that the "Kanmantoo Trough" was part of a marginal sea, extending eastwards to the Stavely volcanic belt of western Victoria. Parker (1986) suggested that the Kanmantoo Group sediments were probably deposited in an extensional tectonic regime on a marginal shelf reflecting tectonic activity to the west and a continental margin to the east. Powell (1990) regarded the "Kanmantoo Fold Belt" as representing the westernmost part of the "Tasman Fold Belt". He suggested that the Kanmantoo Group represents passive margin sedimentation.

The term Truro Volcanics was defined by Forbes *et al.* (1972) from a type section in Levi Creek, 11 km north of Truro (Fig. 1). They included two units within the Truro Volcanics (Fig. 2), with the lower unit comprising a 240 m thick sequence of interbedded volcaniclastic sediments, amygdaloidal volcanics and limestones. The upper unit as described by Forbes *et al.* comprises 60 m of marble, shaly marble, metasiltstone and a thin (2 m) horizon of porphyritic andesite. Forbes *et al.* (1972) noted that this sequence is overlain by the Heatherdale Shale which, near the base, contains clasts of volcanic rocks. However, the exact nature of the contact is unclear due to poor exposure. The Heatherdale Shale, the top unit of the Normanville Group, is overlain by the Carrickalinga Head Formation, the basal unit of the Kanmantoo Group. Forbes *et al.* (1972) suggested that the marble in the upper member of the Truro Volcanics is

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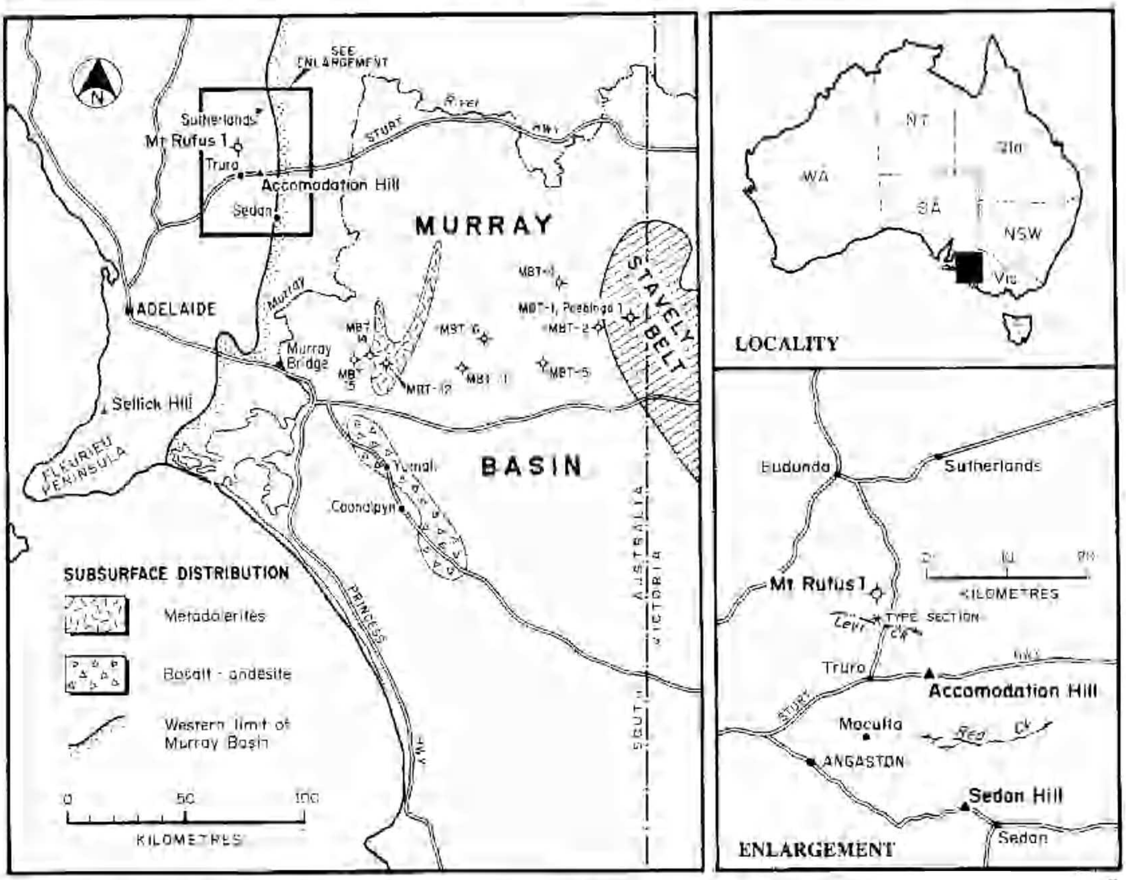

Fig. 1. Locality Map. The type section of the Truro Volcanics is 2 km south of Mt Rufus 1.

equivalent to the Fork Tree Limestone which at Sellick Hill conformably underlies the Heatherdale Shale (Daily 1963).

Rocks assigned to the Truro Volcanics by previous workers occur in outcrop only in the Karinya Syncline, north-east of Adelaide as shown by Cobb & Farrand (1984). A recent report which may extend the known distribution of the Truro Volcanics is that of Polomka (1988)[1] who reported float material of possible Truro Volcanics about 2 km NNE of Moculta, near the base of what he mapped as Carrickalinga Head Formation. However, the exact stratigraphic position of these rocks is doubtful because of the poor outcrop in the area. Polomka described the rock as comprising fine to medium grained phenocryst pseudomorphs of epidote (2%), within a very fine actinolite (45%) and epidote (30%) groundmass.

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TRURO VOLCANICS TYPE SECTION

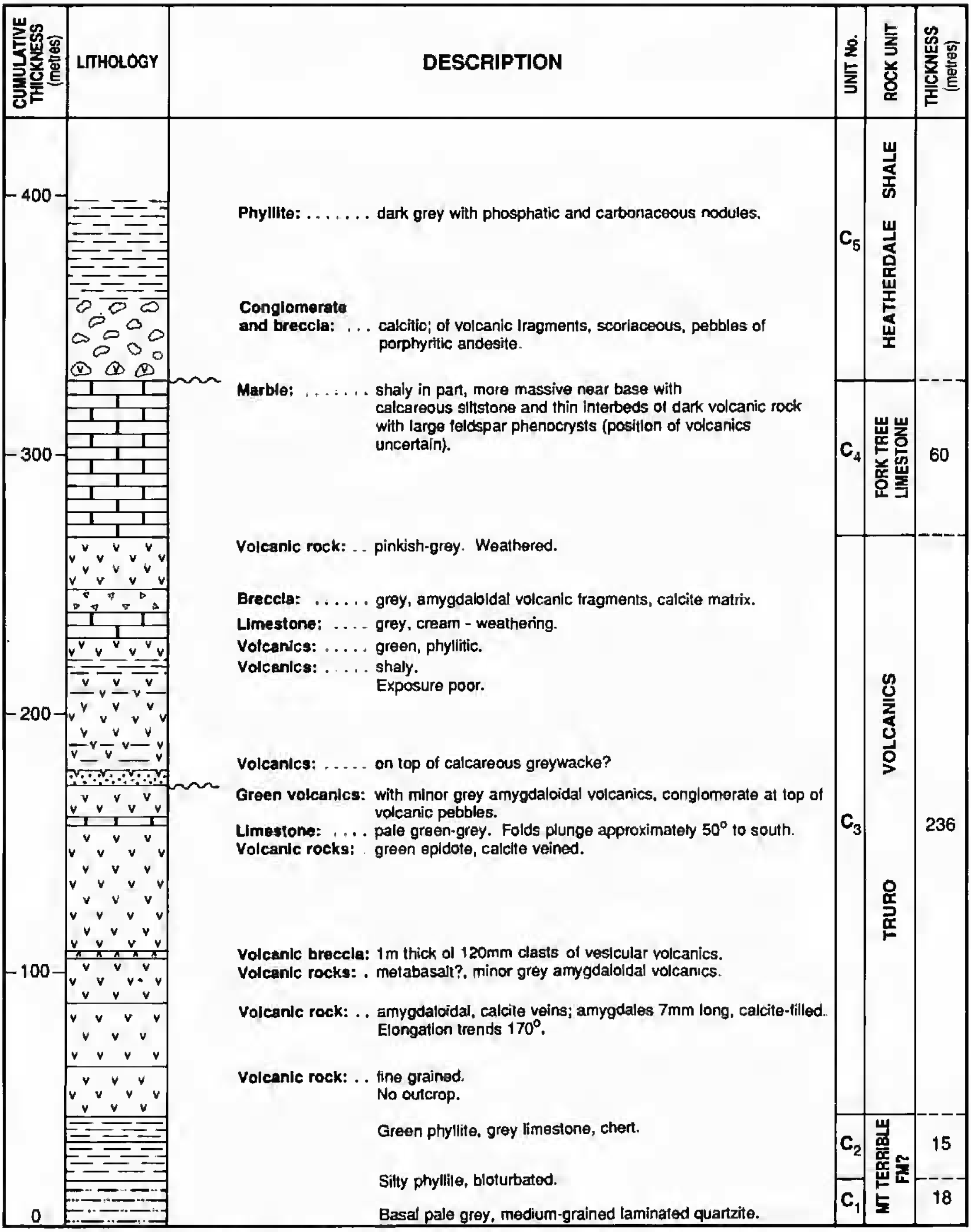

Fig. 2. Stratigraphic section at type section of Truro Volcanics, 11 km north of Truro (after Forbes *et al.* 1972).

At the extreme eastern edge of the Mt Lofty Ranges, Early Cambrian volcanics have been recorded at Sedan Hill (Cooper & Gatehouse 1988[2]; Gatehouse *et al.* 1990), at Red Creek (Gatehouse *et al.* 1991a[3]; McCulloch 1990[4]; Van der Stelt 1990[5]), Accomodation Hill (Forbes *et al.* 1972) and near Sutherlands (Forbes *et al.* 1972). The best exposure of Early Cambrian volcanics from the eastern Mt Lofty Ranges are those mapped in Red Creek by Coats & Thomson (1959) as feldspar porphyrite. The remainder of this paper deals largely with the Red Creek area, north-west of Sedan (Fig. 1).

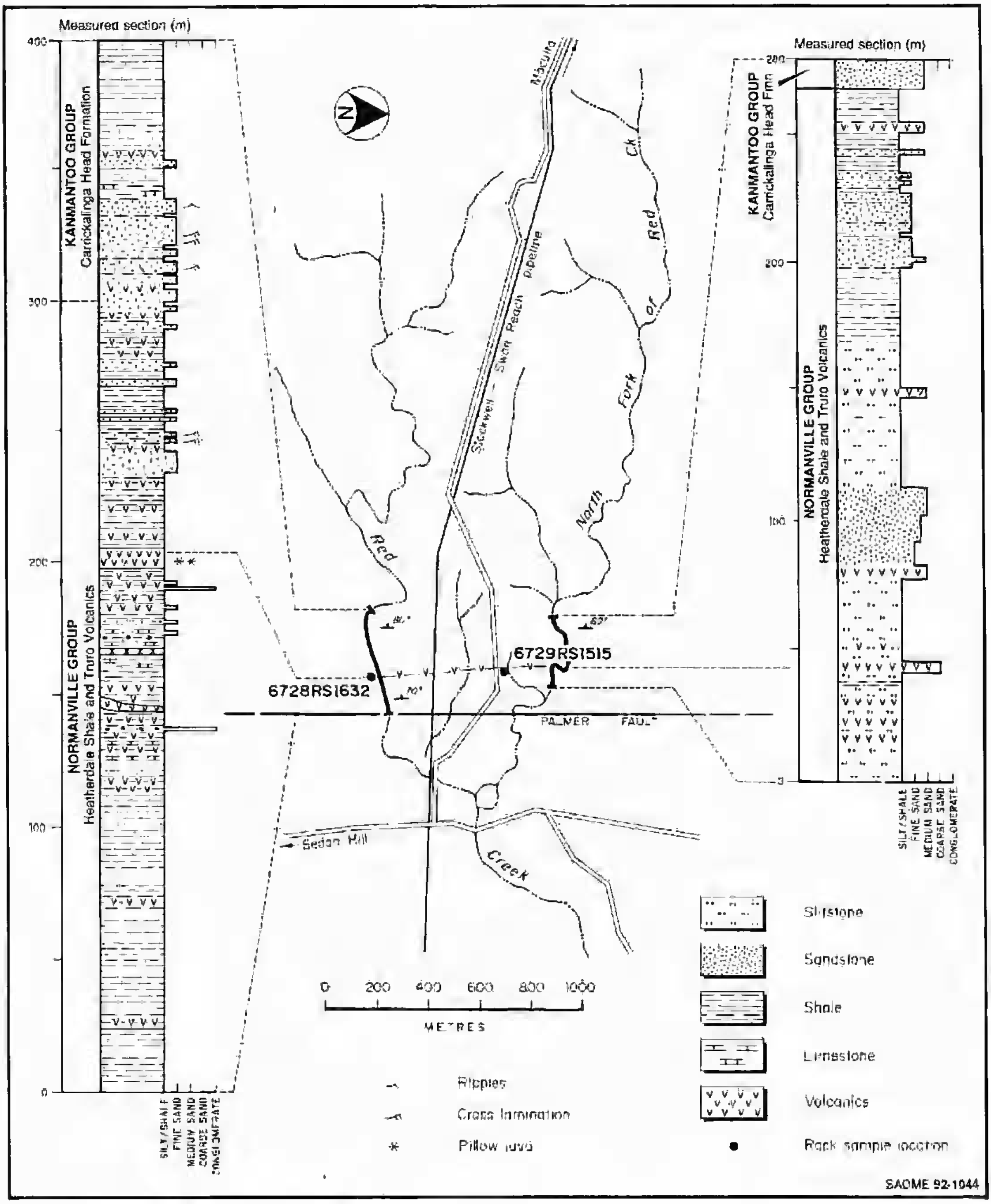

Fig. 3. Stratigraphic section at Red Creek.

Stratigraphic setting

Detailed measured sections at Sedan Hill (Cooper & Gatehouse 1988) and at Red Creek (Gatehouse *et al.* 1991a[3]) show that volcanic rocks, generally referred to as the Truro Volcanics are interbedded within the Heatherdale Shale and continue into the basal parts of the gradationally overlying Carrickalinga Head Formation. The Red Creek section has been logged in some detail (Gatehouse *et al.* 1991b[6]); only a summary of the section is given here (Fig. 3).

About 300 m of Heatherdale Shale is exposed at Red Creek; the base is not exposed due to the presence of the Palmer Fault. As exposed at Red Creek the Heatherdale Shale is a pale grey laminated phyllite which becomes darker and less micaceous up-section. There are minor calcareous siltstone horizons. Within these units are thin tuffaceous and/or volcanogenic siltstone horizons which become increasingly abundant up-section.

About 200 m above the base of the measured section are several basaltic lava flows, one of which exhibits pillows (Fig. 4). The pillowed flow has an uneven base and cuts down into an underlying 0.2 m thick tuff horizon; it appears to thin to the south. It contains several pillow structures with chilled margins and triple junctions (Fig. 4). An intrusive igneous body seen between 145 and 150 m on the measured section may represent a feeder pipe to the lavas higher in the section. Above the pillow lavas the tuffaceous/volcanogenic siltstone horizons continue with reduced frequency into the basal 60 m of the gradationally overlying Carrickalinga Head Formation. Detailed descriptions of the complete stratigraphic section will be given in a later paper.

In the north branch of Red Creek (Fig. 3), close to the base of the Carrickalinga Head Formation, there are several beds, and/or blocks, of crystal tuff comprising almost pure feldspar crystals clearly winnowed from enclosing ash. Such beds may have formed by current activity at the site of deposition or by differential air-fall separation.

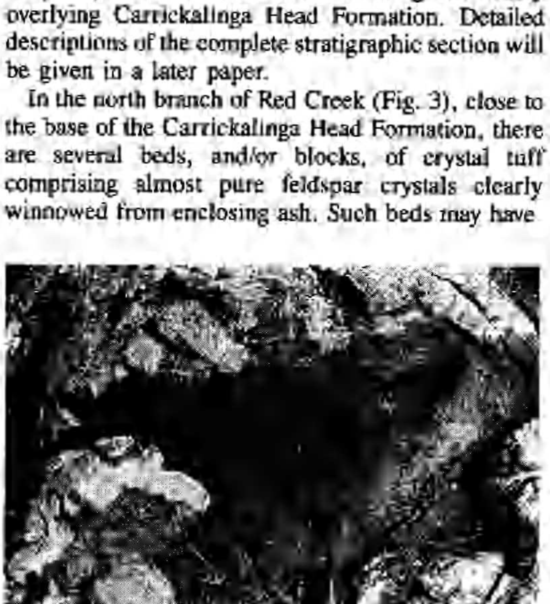

Fig. 4. Pillow lavas at Red Creek. Note the triple junction at centre left.

Regional stratigraphic interpretation

As noted above, in Red Creek, lavas and volcanogenic sediments extend thorugh the exposed Heatherdale Shale up into the base of the Carrickalinga Head Formation. However, near the type section (Fig. 2) of the Truro Volcanics 24 km NNW of Red Creek, the highest known volcanics are at least 200 m below the top of the Heatherdale Shale (see map in Forbes *et al.* 1972 and Fig. 2 herein). Indeed Forbes *et al.* (1972) suggest that the bulk of the volcanics in the type area occurs below an equivalent of the Fork Tree Limestone, which on Fleurieu Peninsula lies conformably below the Heatherdale Shale. However, since this correlation with the Fork Tree Limestone is made on lithological grounds only, and further, that there are calcareous horizons within the Heatherdale Shale both on Fleurieu Peninsula and at Red Creek, then there may be some doubt about the correlation. It could be argued that the marble of the type area of the Truro Volcanics, described as Unit C4 by Forbes *et al.* (1972), is equivalent to the calcareous horizons found in the Heatherdale Shale at Red Creek rather than being equivalent to the Fork Tree Limestone. However, if the correlation of the Unit C4 marble in the type section to the Fork Tree Limestone is correct then it suggests that the volcanics at Red Creek are in a higher stratigraphic position than those of the type section and should not be referred to the Truro Volcanics. In his discussion on the Stansbury Basin, Gravestock (in press) has included all these volcanics as Truro Volcanics. A further complication is the almost complete lack of exposure of the basal 150 m of the Heatherdale Shale near the type section of the Truro Volcanics. The recent drilling of Mt Rufus No. 1 stratigraphic hole 2 km north of the type section suggested that there may be several unrecognised faults in the area (Gatehouse *et al.* 1991b[6]). Until the position is clarified the volcanics described herein are simply referred to as the volcanics from Red Creek.

Elsewhere in the Stansbury Basin, green tuff beds in the Parara Limestone may be correlated with the Truro Volcanics of the Karinya Syncline (Gravestock in press). A tuff bed from within the Heatherdale Shale at Sellick Hill has been dated at 526±4 Ma (Cooper *et al.* 1992); this tuff may also be equated with the Truro Volcanics or the volcanics at Red Creek or with neither.

Petrography of volcanics at Red Creek

In hand specimens the volcanics in Red Creek have a grey fine grained ground mass with distinctive large (approximately 0.5 mm diameter) phenocrysts of feldspar (up to approximately 25%) and minor iron staining. The rocks show variable intensities of tectonic foliation.

In thin section it appears that the phenocrysts are predominantly of zoned plagioclase although approximately 10% of the phenocrysts are of an alkali feldspar. The groundmass is predominantly of acicular feldspar laths producing a trachytic texture. The tectonic fabric of these rocks varies from slight to intense foliation, the feldspar phenocrysts having rotated parallel to the foliation. Alteration is pervasive with sericitisation of the feldspar and chlorite/iron-oxide replacement of mafic minerals. Sporadic veinlets of quartz and calcite cross-cut this rock. Petrologically the lavas classify as trachytic basalt.

Geochemistry of volcanics at Red Creek

Two samples (6728 RS 1632 and 6729 RS 1515) of massive pillow lava were taken from separate localities near Red Creek and geochemically analysed for a comprehensive suite of elements (Tables 1 and 2). Several analytical methods were used, including:

ICP (acid digestion) — major elements
XRF — As, Ba, Bi, Sb, Sn, V, Zr
Atomic Absorption Spectrography — Ag, Cr, Cu, Ni, Pb, Zn
Fire Assay — Au, Pt, Pd
ICP Mass Spectrography — Ce, Dy, Nd, Er, La, Eu, Lu, Yb, Y, Sm, Gd, U, Th, Sr, W, Ta, Mo, Nb, Ga, Co, Cs, Rb.

The two geochemical analyses (Tables 1 and 2) of the pillow lava reflect their described lithology, as basaltic lavas that have undergone greenschist facies metamorphism. Elevated loss on ignition (LOI) values (average 11.5%) attest to alteration effects resulting in hydration. Clearly the present chemical composition of the lavas at Red Creek is not primary, as the volatile content is significantly higher than in analogous fresh rocks. This is to be expected from the presence of

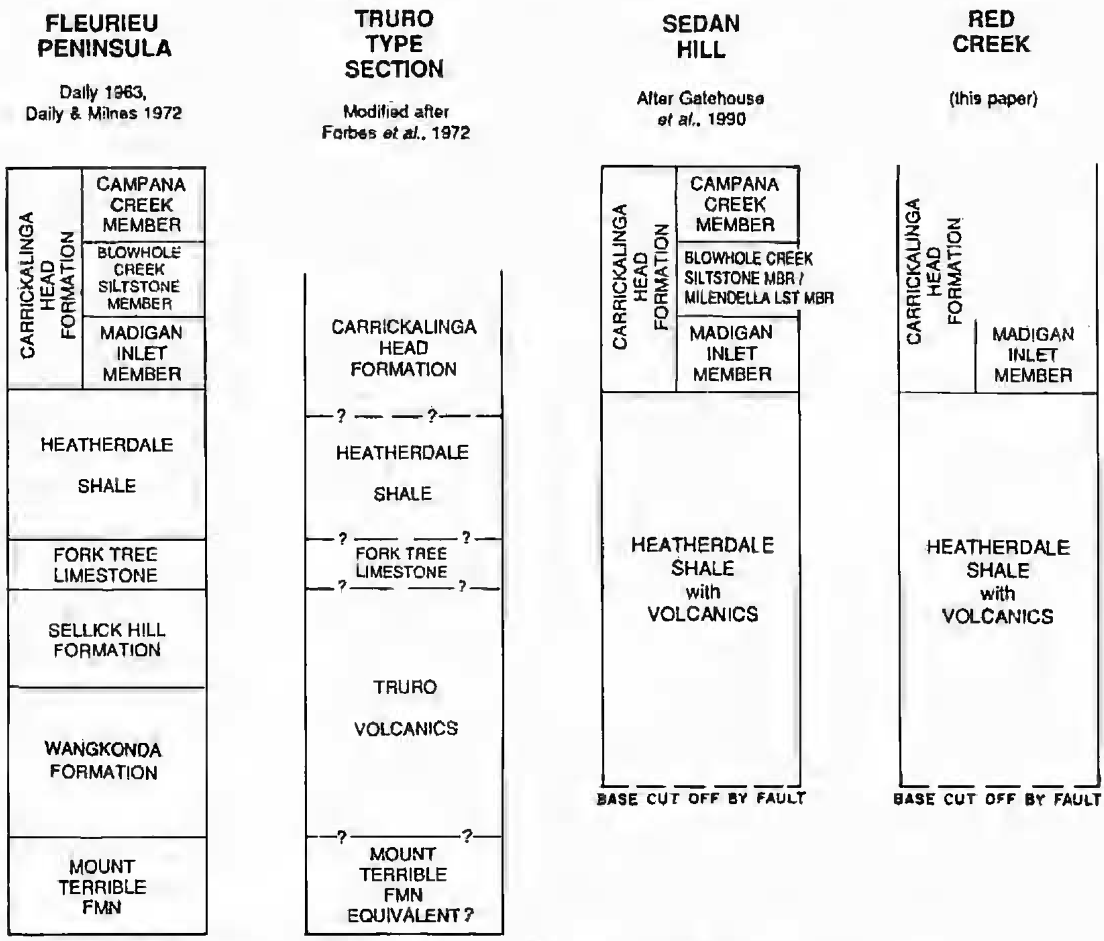

Fig. 5. Correlation diagram of the Cambrian sequences of the Red Creek-Truro-Sellick Hill areas

TABLE 1. Geochemical analyses and CIPW norms. N.B. CIPW weight % norms are calculated from analyses recalculated to 100% free of H_2O and CO_2; cc is not recalculated, Fe data is recalculated using a Fe_3: Total Fe cation ration of 0.20.

Major Elements in Percent			CIPW Weight % Norms		
	6728 RS 1632	1515		6728 RS 1632	1515
SiO_2	42.30	42.30	ab	18.85	19.92
TiO_2	2.42	2.24	or	19.71	13.69
Al_2O_3	15.80	14.40	an	18.47	15.31
Fe_2O_3	8.75	8.05	ne	9.85	13.22
FeO			di	18.11	23.15
MnO	0.28	0.26	ol	4.67	3.21
MgO	2.64	3.32	mt	2.94	2.72
CaO	8.05	8.85	il	5.32	4.95
Na_2O	3.78	4.50	ap	2.09	1.73
K_2O	2.88	1.99			
P_2O_5	0.78	0.66	Total	100.01	100.01
H_2O+					
H_2O					
CO_2					
LOI	10.80	12.30			
Total	98.48	98.87	DI	48.41	46.82

=not analysed, DI=Differentiation Index

hydrous secondary minerals in these lavas. Similar alteration of mafic lavas in the Victorian greenstone belts (Crawford & Keays 1978) is considered to have caused hydration, along with slight addition of CO_2 and Na_2O accompanied by leaching of SiO_2, CaO, Al_2O_3 and K_2O. However, the degree of chemical change was considered to be minimal, and magmatic trends were clearly visible. To minimise the effect of hydration dilution and related chemical mobility, plots using elements considered immobile during alteration are used and analyses are recalculated to 100% volatile-free prior to plotting.

The lava at Red Creek plot on the border between phono-tephrite and tephrite-basanite close to the basaltic-trachyandesite field in the SiO_2 versus Na_2O+K_2O classification plot of Le Bas *et al.* (1986; Fig. 6). In the Nb/Y versus Zr/TiO_2 classification plot (Winchester & Floyd 1977; Fig. 7) using elements considered immobile during alteration, the lavas classify as alkali basalt.

To further define the alkaline basalt a classification scheme devised for the Tertiary alkaline volcanics of eastern Australia (Johnson 1989) based on CIPW norms was utilised (Fig. 8). Using this classification scheme the division between sub-alkaline and alkaline mafic lavas is that alkaline lavas have <10% normative hypersthene; on this basis the basalts in Red Creek classify as alkaline and plot within the field of hawaiites. The presence of considerable levels (9.85 and 13.22%) of normative nepheline suggests these rocks are silica undersaturated. However, plots using immobile elements (Fig. 7) suggest these lavas have not attained silica undersaturation but show that the lavas at Red Creek and the Truro Volcanics at Mt Rufus 1 (Gatehouse *et al.* 1991b[6]) belong to a group of analyses that straddle the boundary between alkali basalt and silica undersaturated nepheline/basanite fields.

The analyses agree with field evidence suggesting that the lava at Red Creek represents a single thin submarine lava sequence from a common source, in that they plot close together on all classification plots.

The lavas plot outside the tectonic discrimination fields of Pearce & Cann (1973; Fig. 9), although closest to the intraplate field; and in marked contrast to the MORB-related metadolerites that occur in the Murray Basin basement (Rankin *et al.* 1991a, b[7,8]) and as sills and dykes in the Mt Lofty Ranges (Liu & Fleming 1990; Rankin *et al.* 1991a[7]). On a MORB normalised spidergram (Fig. 10) the Red Creek lava shows a distinctive trend of elemental enrichment relative to MORB values of the incompatible elements from Sr through to Ni, which is typical of the more silica

TABLE 2. Trace elements in ppm.

	6728 RS 1632	6729 RS 1515	Detection limit (ppm)
Ag	<1.00	<1.00	1
As	64.00	72.00	2
Au	2.00B	7.00B	1B
Ba	880	610	10
Bi	4.00	<4.00	4
Ce	82.00	78.00	0.1
Co	29.00	44.00	1
Cr	110	105	4
Cs	1.80	1.20	0.2
Cu	6.00	5.00	2
Dy	8.00	7.20	0.1
Er	3.90	3.30	0.1
Eu	2.80	2.50	0.1
Ga	26.00	20.00	1
Gd	9.00	8.60	0.1
La	38.00	36.00	0.1
Lu	0.60	0.50	0.1
Mo	4.00	3.55	0.5
Nb	76.00	66.00	0.5
Nd	44.00	42.00	0.1
Ni	52.00	54.00	4
Pb	12.00	12.00	4
Pd	1.00B	<1.00B	1B
Pt	<5.00B	<5.00B	5B
Rb	82.00	60.00	0.2
Sb	<4.00	4.00	4
Sm	9.60	8.80	0.1
Sn	<4.00	10.00	4
Sr	240	255	0.1
Ta	3.00	2.20	0.2
Th	4.80	3.60	0.1
U	2.60	2.20	0.1
V	<5.00	<5.00	5
W	3.00	3.00	1
Y	34.00	29.5	0.1
Yb	3.70	3.00	0.1
Zn	22.00	26.00	2
Zr	380	320	4

B=ppb

undersaturated alkaline mafic lavas of such provinces as the Tertiary eastern Australian volcanic province (Johnson 1989); note the marked contrast of the alkaline intraplate lavas with MORB related metadolerite from MB-12 in the Murray Basin basement (Rankin *et al.* 1991a[7] and b[8]).

Other alkaline volcanic areas similar to Red Creek include the Yumali/Coonalpyn area, the Peebinga-1

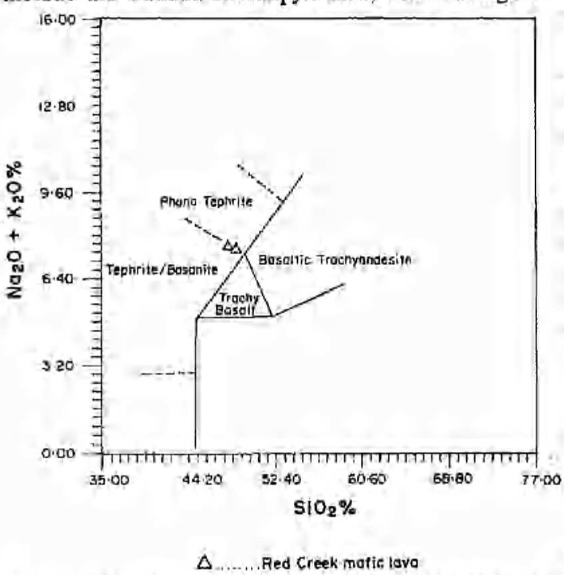

Fig. 6. Red Creek lavas on part of classification plot of Le Blas *et al.* (1986). Values calculated to 100% volatiles free.

(MBT-1) drillhole into the northwestern termination of the magnetically defined Mt Stavely Belt (Rankin *et al.* 1991a[7], b[8]), and the Truro Volcanics as defined in Mt Rufus 1 drillhole (Gatehouse *et al.* 1991b[6]; Fig. 10). Of the other volcanics the nearest are the Truro Volcanics that crop out on the west limb of the Karinya Syncline 22 km NW of Red Creek; the lavas at Red Creek represent a more evolved lava type than the Truro Volcanics in their type section, resulting in a line more distant from MORB in Fig. 10. This chemical difference is seen in the petrology where the lavas at Red Creek are distinctively porphyritic with phenocrysts of alkali feldspar.

The Red Creek analyses are compared with a classic continental intraplate volcanic suite in Fig. 11, where they are normalised to Karoo type basalts, the lavas at Red Creek and the other Cambrian alkaline volcanics noted above exhibit enrichments relative to Karoo basalt of the elements Sr to Ti, with Red Creek being one of the most chemically evolved suites. This supports the field relations which suggest that these lavas are not directly analogous to the thick piles of dominantly tholeiitic basalt fissure lavas of the Karoo Province, but rather are more closely analogous to the more localised central complexes seen in intraplate alkaline volcanic complexes (Johnson 1989).

In summary, it is proposed that the lava at Red Creek represents a single flow of hawaiite composition from a central volcanic complex, closely analogous to that of the Truro Volcanics but not necessarily from the

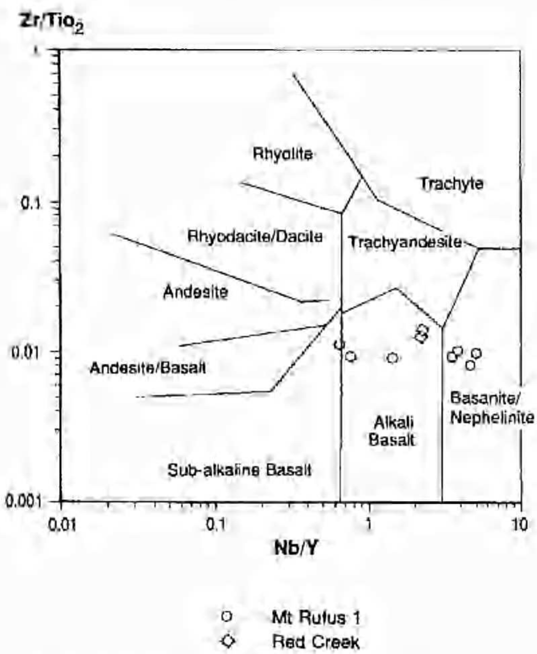

Fig. 7. Red Creek and Mt Rufus 1 lavas on part of classification plot of Winchester & Floyd (1977).

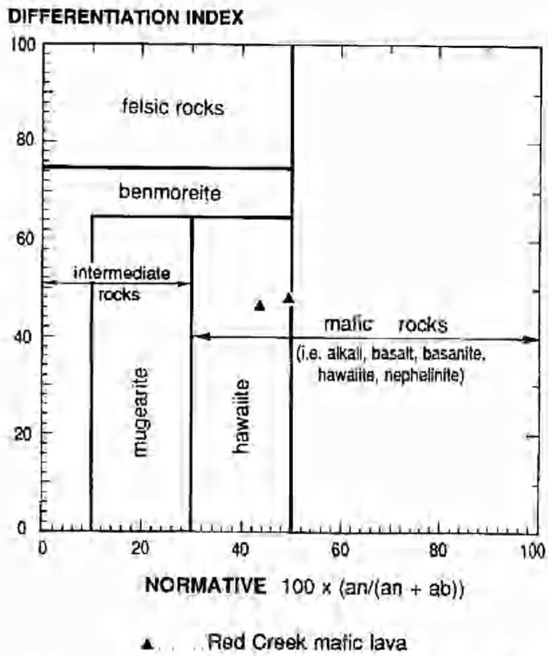

Fig. 8. Red Creek lavas on CIPW normative classification plot for sub-alkaline intraplate lavas (Johnson 1989).

same centre or erupted at exactly the same time. However, both the lava at Red Creek and the Truro Volcanics undoubtedly belong to the same Early Cambrian alkaline 'within plate' volcanic province, which may be genetically linked to other Cambrian-mafic alkaline provinces such as the Yumali/Coonalpyn and Peebinga-1 areas (Rankin *et al.* 1991a[7] and b[8]). The closest tectonic analogue for these provinces is that of a rifted continental margin as proposed for the Tertiary intraplate volcanic province of eastern Australia (Johnson 1989); metadolerites which post-date the volcanics indicate a change with time from intraplate to MORB type composition (Liu & Fleming 1990) indicating an ensuing period of crustal thinning and major dyke emplacement, associated rifting and crustal extension.

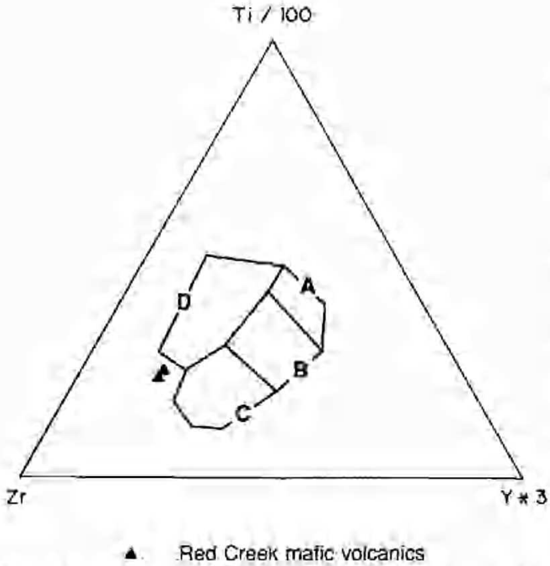

Fig. 9. Red Creek volcanics on tectonic discrimination plot of Pearce & Cann (1973). "Within plate" basalts plot in field D, Morb (ocean floor basalts) in field B, Iow Ktholeiites in field A and B, calc-alkaline basalts in fields C and B.

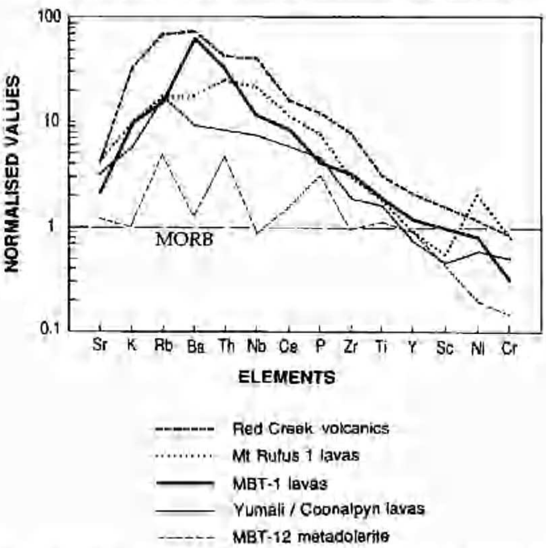

Fig. 10. MORB normalised spidergram for averages of possible Cambrian mafic suite from the Murray Basin basement and the Cambrian lavas of the Mt Lofty Ranges.

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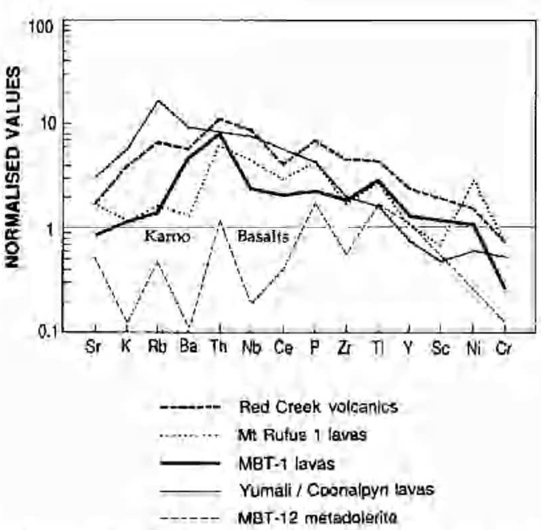

Fig. 11. Karoo Basalt normalised spidergram for averages of possible Cambrian mafic suites from the Murray Basin basement and the Cambrian lavas of the Mt Lofty Ranges.

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